Ant Colony Optimization based PID for single Area Load Frequency Control

M. Omar, M. Soliman, A. M. Abdel Ghany, and F. Bendary

Abstract—**In this paper a novel Artificial Intelligence technique known as Ant Colony Optimization (ACO) is used for optimal tuning of PID controller for load frequency control. The system proposed here is a single area with reheat thermal system containing nonlinearities represented by Generation Rate Constraint (GRC), dead band and wide range of parameters. Three different cost functions have been suggested for tuning the PID controller. The closed loop response using these values of PID gains has been compared with Ziegler-Nichols (ZN) tuned one, the system has been tested for various load changes to reveal the effectiveness of the proposed technique.**

Index Terms—**Load Frequency Control (LFC), PID Controller.**

I. Introduction

WITH large scale power systems, Load Frequency Control (LFC) performs great function to maintain mainly the frequency deviation and tie line powers followed by load changes (either increment or decrement) at zero and pre specified values respectively. These important functions are delegated to LFC due to the fact that a well-designed power system should maintain voltage and frequency at scheduled range while providing an acceptable level of power quality [1]. LFC is considered as one from the main operations for any power system. Usually LFC is organized in three levels:

• Primary control is done by governors of the generators, which provide immediate action to sudden change of load.

• Secondary control keeps frequency at its nominal value by adjusting the output of selected generators (controller is needed).

• Tertiary control is an economic dispatch that is used to operate the system as economically as possible [2]. During the last years several researches and techniques had been applied to the field of LFC. A robust LFC via H∞ and H2 control theories has been designed in [3] with different cases for the norm between load disturbance and frequency deviation output. The main disadvantage of these two methods is that these introduce a controller with the same plant order, which in turn doubles the order of the open loop system, and makes the process very complex specially for large scale interconnected power systems. In [4] another technique had been suggested for tuning the parameters of a PID controller for LFC in a single area power system by using particle swarm optimization (PSO). Genetic Algorithm (GA) [5] also used in this field for the purpose of selection of a PID parameters. In [6] LFC with fuzzy logic controller (FLC) considering nonlinearities and boiler dynamics is introduced which has greatly improved the performance of the controller. In [1] new approach using Imperialist Competitive Algorithm (ICA) for multi area LFC has been introduced. Another method for tuning PID controller using Bacteria Foraging Optimization (BFO) for two area system with different step load changes has been applied in [7].

This paper proposes a new optimization technique known as ACO for optimal tuning of PID controller. The motivation behind this research is to prove and demonstrate the effectiveness and robustness of ACO technique based PID under several loading conditions in presence of nonlinearities. The paper is organized as follows: Section I, introduction. A brief description for ACO technique is illustrated in Section II. Section III, focuses on the modeling of single area power system including nonlinearities. In Section IV, simulation and results obtained from the application of ACO tuned PID on the system. Sections V, conclusion.

II. Ant Colony Optimization: Overview

The ant colony optimization algorithm (ACO) is a probabilistic technique for solving computational problems which can be reduced for finding good paths through graphs. This algorithm is a member of the ant colony algorithms family, in swarm intelligence methods, and it constitutes some metaheuristic optimizations. Initially proposed by Marco Dorigo in 1992 in his PhD thesis [8]. The first algorithm was aiming to search for an optimal path in a graph, based on the behavior of ants seeking a path between their colony and a source of food. The original idea has since diversified to solve a wider class of numerical problems, and as a result, several problems have emerged, drawing on various aspects of the behavior of ants. In the natural world, ants (initially) wander randomly, and upon finding food return to their colony while laying down pheromone trails. If other ants find such a path, they are likely not to keep travelling at random, but to instead follow the trail, returning and reinforcing it if they eventually find food. Over time, however, the pheromone trail starts to evaporate, thus reducing its attractive strength. The more time it takes for an ant to travel down the path and back again, the more time the pheromones have to evaporate. A short path, by comparison, gets marched over more frequently, and thus the pheromone density becomes higher on shorter paths than longer ones [9]. Figure (1) [10] illustrates the behavior of real ants in searching the source of food, it proves also that shorter paths have larger pheromone concentrations, so more ants tend to travel in these paths.

M. Omar, M. Soliman, and F. Bendary are with the Department of Electrical Engineering, Benha university, Cairo, Egypt (e-mail: engmahmoudomar_10@yahoo.com).

M. Mohamed. is with the Department of Electrical Engineering, Helwan University, Helwan, Egypt.

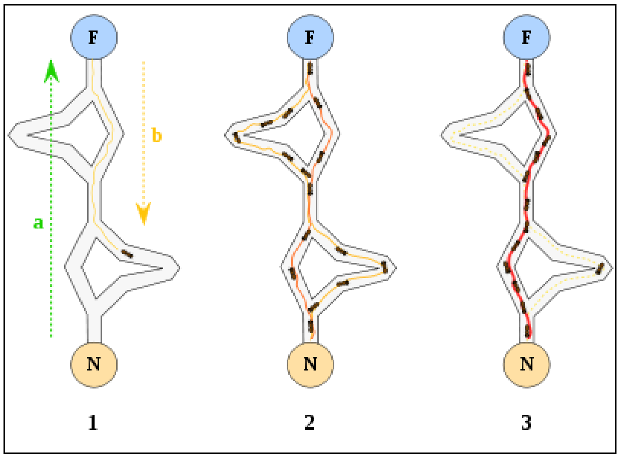

Fig. 1. Ants from nest to the source of food.

Advantages of ACO technique represent in:

- Positive Feedback accounts for rapid discovery of good solutions.
- Distributed computation avoids premature convergence.
- The greedy heuristic helps finding acceptable solution in the early solution in the early stages of the search process.

Disadvantages of ACO on the other hand represent in:

- Slower convergence than other Heuristics.
- Performs poorly for problems have larger than 75 nodes.
- No centralized processor to guide the ACO towards good solutions [11].

In this paper ACO algorithm is used for optimal tuning of PID parameters k_p, k_i and k_d, by minimizing the required cost function. A flowchart for this optimization process is shown in fig (2).from this chart one can deduce that the stopping process of the algorithm is related to the maximum number of iterations not any other factor, as it reached, the algorithm will stop.

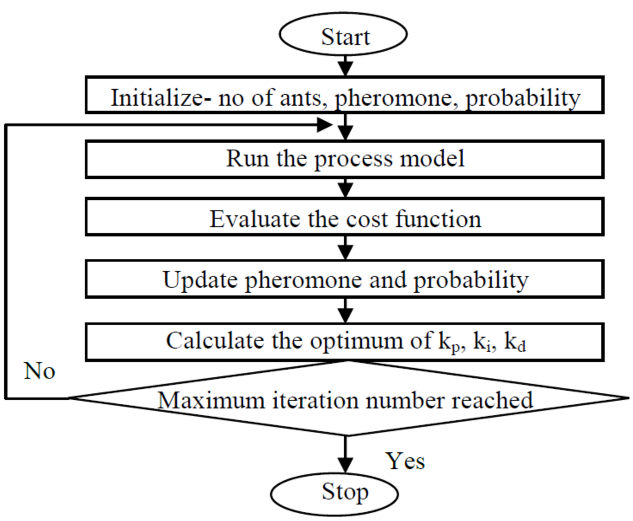

Fig. 2. Flowchart of ACO based PID control system.

III. SINGLE AREA POWER SYSTEM

A. System Model

A single area model of a reheat thermal power station including nonlinearities is shown in fig (3). A complete description for symbols used in the block diagram is given in table I.

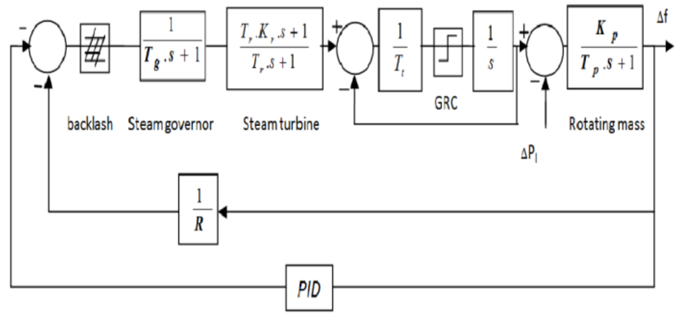

Fig. 3. Block diagram of single area model.

TABLE I
SYMBOLS IDENTIFICATION

Symbol	Quantity	Value
T_g	Governor Time constant of thermal area	0.08 s
T_r	Reheat time constant	10 s
K_r	P.u megawatt rating of high pressure stage	0.5
T_t	thermal turbine time constant	0.3 s
K_p	thermal plant gain	120 HZ/p.u MW
T_p	thermal plant time constant	20 s
R	Regulation constant	2.4Hz/p.u Mw

This model neglecting boiler dynamics, as well as steam chest time constant which is related to nonreheat stage, as it ranges from 0.1 to 0.5s whereas the time constant for the reheat stage (which is series cascaded with the nonreheat stage) ranges from 4 to 10s. Nonlinearities incorporated in this model represent in GRC and governor dead band (backlash). The first one as its name implies (GRC) respects for the turbine illustrates the limitation on the generation rate of change in the output generated power due to the limitation of thermal and mechanical movements [12], for thermal stations it is taken to be 0.1 p.u Mw per minute [13]. The second nonlinearity is defined as the total magnitude of a sustained speed change; within which there is no resulting change in valve position. All types of governors have a dead band in response, which is important for power system frequency control in the presence of disturbances, here it is taken to be .0005 [13].

B. Control Technique

The controller type used here is PID controller with the structure shown in (1):

$$k(s) = k_p + k_i / s + k_d s \quad (1)$$

Where k_p, k_i, k_d are proportional, integral and differential gains respectively. With Δf as the input to this controller as shown in (2).

$$u(s) = -k(s) * \Delta f \quad (2)$$

The function of each part of a PID controller can be described as follows, the proportional part reduces the error responses of the system to disturbances, the integral part eliminates the steady-state error, and finally the derivative part dampens the dynamic response and improves the system stability [14].

C. Cost Function

Three cost functions had been suggested for ACO technique for tuning the parameters of the PID controller.

First cost function:

This cost function as shown in (3) minimizes the integrated square error e (t).

$$f_1 = \int_0^\infty (e(t))^2 \, dt \quad (3)$$

Second cost function:

In this method [15], the actual closed-loop specification of the system with controller, rise time (t_r), maximum overshoot (M_p), settling time (t_s), and steady state error (e_{ss}) are used to evaluate the cost function. This is done by summing the errors between actual and specified specifications as given by (4).

$$f_2 = \frac{1}{[c_1(t_r - t_{rd}) + c_2(M_p - M_{pd}) + c_3(t_s - t_{sd}) + c_4(e_{ss} - e_{ssd})]} \quad (4)$$

Where, c_1: c_4 are positive constants (weighting factors), their values are chosen according to prioritizing their importance, (t_{rd}) is the desired rise time, (M_{pd}) is the desired maximum overshoot, (t_{sd}) is the desired settling time, and (e_{ssd}) is the desired steady state error.

Third cost function:

A performance criterion in the time domain is proposed as given in (5).

$$f_3 = \frac{1}{(1 - e^{-\beta})(M_p + e_{ss}) + e^{-\beta}(t_s - t_r)} \quad (5)$$

This cost function can satisfy the designer requirements using the weighting factor value (β). The factor is set larger than 0.7 to reduce the overshoot and steady-state error. On the other hand is set smaller than 0.7 to reduce the rise time and settling time [15]. All of these cost functions have been minimized subjected to:

$$k_p^{\min} \le k_p \le k_p^{\max}$$
$$k_i^{\min} \le k_i \le k_i^{\max}$$
$$k_d^{\min} \le k_d \le k_d^{\max}$$

The range of parameters k_p, k_i and k_d should be selected from the stability point of view. A comparison was made between ACO tuned PID with another one tuned using ZN [4].

IV. SIMULATIONS AND RESULTS

In this section the different values of PID parameters tuned using ACO technique for the early mentioned three cost functions are shown in table (II) with those tuned using (ZN) method.

TABLE II
VALUES OF PID GAINS

	k_p	k_i	k_d
1st cost function	5	7.5	28
2nd cost function	2.5	27.5	15.5
3rd cost function	5.5	8	47.5
ZN	0.2208	0.0133	0.9163

Different cases of load disturbances are applied to the model to demonstrate effectiveness and robustness of the proposed technique.

Case 1: step load change of +1% has been applied to the system. The response in this case is shown in fig (4). From this response it is clear that ACO tuned PID for the three cost functions has greater performance compared with this one tuned using ZN method. The proposed controller succeeded in damping all oscillations, minimizing settling time and reducing overshoot. It is clear that the response is approximately identical for cost function 1 and 2. The 3rd cost function based PID has the best performance.

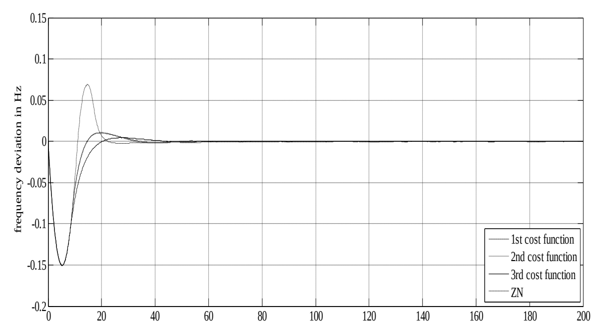

Fig. 4. Frequency deviation response for case 1.

Case 2: in this case the load change increased to reach 5% with system parameters held fixed. This case is considered serious or heavy operating condition. The response shown in fig (5) proves that the proposed controller is still robust and effective under such this disturbance type.

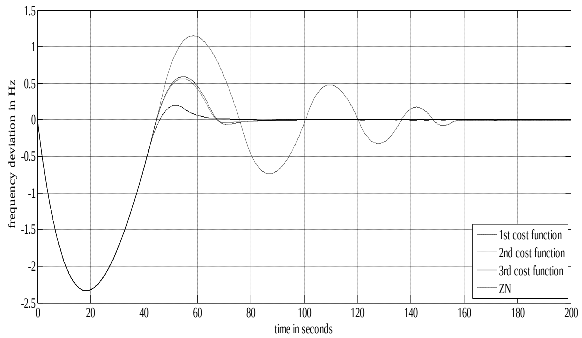

Fig. 5. Frequency deviation response for case 2.

Case 3: in this case we suppose a variation in system parameters specifically 20% increase in Kp and T_p with the same load disturbance in case 2. The response is shown in fig (6) reflects that the controller still retains good performance from the robustness point of view, as the system after all of these stresses is still stable.

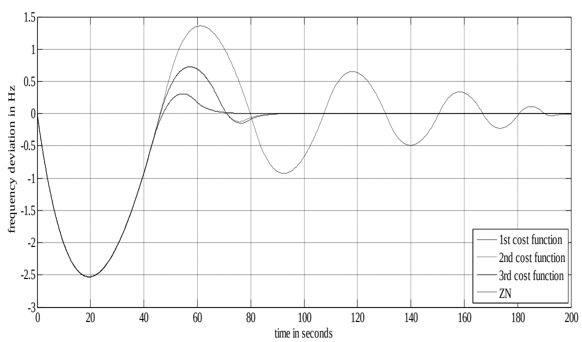

Fig. 6. Frequency deviation response for case 3.

Case 4: another violent test by changing the load disturbance nature from step to impulse wave of 5 seconds duration with 1% load change is applied here. As shown in fig (7) it is clear that the controller succeeded again to stabilize the system with eliminating the steady state error.

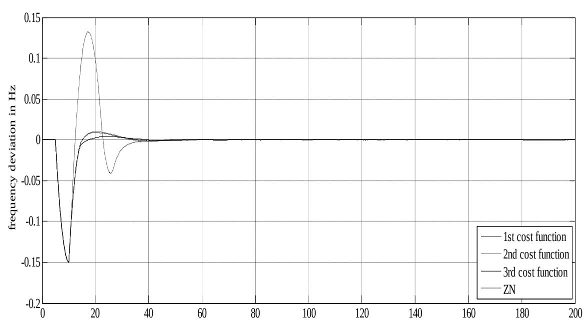

Fig. 7. Frequency deviation response for case 4.

Case 5: this case is considered a simulation for realistic load change case where the load disturbance as shown in fig (8) simulates what happens in fact. For realistic power system load disturbance occurs in ramp shape within certain time not in no time as in step case.

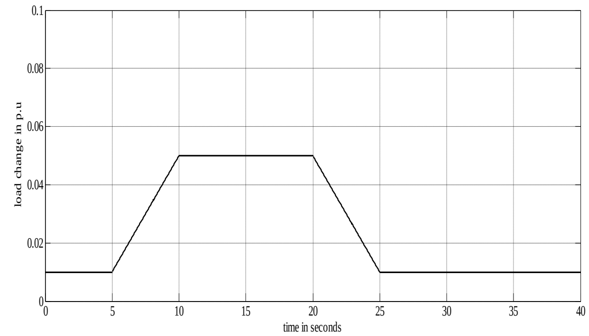

Fig. 8. Load disturbance waveform in case 5.

The response for such type of load disturbance is shown in fig (9). In this case the response using ZN based PID has taken more time to reach steady state and it has larger overshoot compared with those tuned using ACO. The response shown here appears to be different; this is due to the nature of load disturbance, where at the first five seconds the load is constant at 1%, after these five seconds and for another five seconds the load increases linearly to 5%, then the load remains constant at this value for ten seconds and decreases in five seconds again to reach 1%.

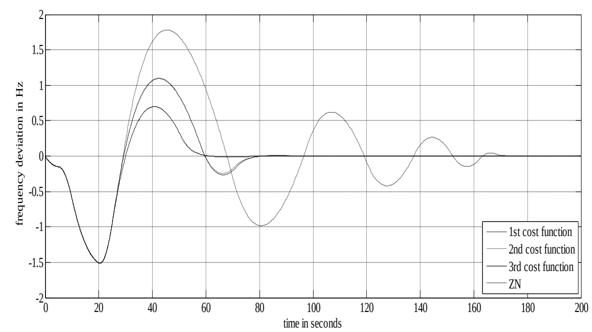

Fig. 9. Frequency deviation response for case 5.

V. CONCLUSION

In this paper a PID controller which is tuned via ACO has been strongly proposed for LFC problem. The results declared that the PID controller which is tuned via ACO is capable to guarantee robust stability and robust performance under various load conditions. From the other hand, simulation results confirmed that the ACO based PID is robust to changes in system parameters and it has excellent performance in compare with the ZN-PID type controller. In future work we intend to apply ACO technique into multi area interconnected power system to reveal its effectiveness for tuning more than one PID at the same time.

APPENDIX

ACO algorithm equations:

$$p_{ij}(t) = \frac{\tau_{ij}(t)^{\alpha}\left(\frac{1}{dij}\right)^{\beta}}{\sum_{j\in nodes}\tau_{ij}(t)^{\alpha}\left(\frac{1}{dij}\right)^{\beta}}$$

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \sum_{\substack{k\in colonythat \\ usededge \\ (i,j)}} \frac{Q}{L_k}$$

Where:

P is the probability.

α, β, τ are parameters related to ACO algorithm.

d is the distance.

Q being a constant parameter.

L_k is the k^{th} ant solution.

ρ is a parameter used to avoid unlimited accumulation of the pheromone trails.

k is the number of ants.

REFERENCES

[1] M. Soroush, M. Ali, S. Mohammad, and A. mohammad, “Tuning of PID Controller for Multi Area Load Frequency Control by Using Imperialist Competitive Algorithm,” ISSN 2090-4304Journal of Basic and AppliedScientific Research ,2012.

[2] TAN Wen, “Load Frequency Control: Problems and Solutions,” Proceedings of the 30th Chinese Control Conference, Yantai, China, July 22-24, 2011.

[3] A. Bensenouci, A. M. Abdel Ghany, “Performance Analysis and Comparative Study of LMI-Based Iterative PID Load-Frequency Controllers of a Single-Area Power System,” WSEAS Transactions on power systems Issue 2, Volume 5, April 2010.

[4] M. Ahmed , “AI-Based Decentralized Load Frequency Controllers for Interconnected Power Systems,” cairo, master of science,2009.

[5] M. E-D. Mandour, E. S. Ali, and M. E. Lotfy, “Robust Load Frequency Controller Design Via Genetic Algorithm and H∞,” Modern Electric Power Systems, Wroclaw, Poland MEPS’10 – paper P16, 2010.

[6] A. Kumar, A. Ahmad, A. Grover, and U. Gupta, “Load Frequency Control Using Fuzzy Logic,” International Journal of Scientific and Research Publications, Volume 2, Issue 7, 1ISSN 2250-3153, July 2012.

[7] E. Salim Ali , S. M. and Abd-Elazim, “Optimal PID Tuning for Load Frequency Control Using Bacteria Foraging Optimization Algorithm,” Proceedings of the 14th International Middle East Power Systems Conference (MEPCON’ 10), Cairo University, Egypt, December 19-21, Paper ID 191, 2010.

[8] A. Colorni, M. Dorigo et V. Maniezzo, “Distributed Optimization by Ant Colonies, ” actes de la première conférence européenne sur la vie artificielle, Paris, France, Elsevier Publishing, 134-142, book style 1991.

[9] M. Dorigo, “Optimization, Learning and Natural Algorithms, ” PhD thesis, Politecnico di Milano, Italie, 1992.

[10] M. Dorigo et L.M. Gambardella, “Ant Colony System : A Cooperative Learning Approach to the Traveling Salesman Problem, ” IEEE Transactions on Evolutionary Computation, volume 1, numéro 1, pages 53-66, 1997.

[11] M. Dorigo, and Th. Stu , “Ant Colony Optimization,” tzle.p. cm."A Bradford book". Includes bibliographical references (p.).ISBN 0-262-04219-3 (alk. paper).

[12] H. Bevrani, “Robust Power System Frequency Control, ” Springer Science+Business Media, LLC, 2009

[13] J.Nanda, A.Mangla, and S.Suri, “Some New Findings on Automatic Generation Control of an I+nterconnected Hydrothermal System with Conventional Controllers,” IEEE Transactions on energy conversion, vol.21,No.1:pp 187-194,Margh 2006.

[14] G. Tan, Q. Zeng, S. He, and G. Cai, “Adaptive and Robust Design for PID Controller Based on Ant System Algorithm,” School of Information Science and Engineering, Central South University Changsha 410083, Hunan Province, P. R. China.

[15] A. Mohamed, “Optimization Techniques for Tuning The Controller of a Permanent Magnet Brushless Motor,” Cairo, master of science, 2012.